MINIMUM SEPARATION DISTANCES CHANGED IN STANDARD

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Regulations & Policy

ABSTRACT

Primary fragmentation distances contribute to two distinct aspects of explosives safety. The first is the maximum fragment range that is used to determine fragmentation distances for intentional detonations. The second is the hazardous fragment distance (1/600 range) that generally controls the Inhabited Building Distance for accidental detonations. The previous guidelines for primary fragmentation distances, as contained in U.S. Department of Defense Explosives Safety Standards (DoD 6055.9-STD, July 1999), are explained for both intentional and accidental detonations. The specified minimum separation distances in DoD 6055.9-STD have recently been changed (July 2000). These changes are based on algorithms for the computation of primary fragmentation distances developed and published by the U.S. Army Engineering and Support Center, Huntsville. These algorithms are described in this paper. The new minimum separation distances and their impact on explosives safety are discussed.

PREVIOUS U.S. REQUIREMENTS

INTENTIONAL DETONATIONS.

Until recently (June 2000), U.S. Department of Defense (DoD) explosives safety standards[1], gave the following guidance for minimum separation distances for non-essential personnel: " *Distance (Feet) = 328W$^{1/3}$, but not less than 2500 feet, for fragmenting explosive materials. For bombs and projectiles with caliber 5 inches or greater use a minimum distance of 4000 feet. The maximum fragment throw range (including the interaction effects for stacks of items or single items, whichever applies), with an appropriate safety factor, may be used to replace the 2500 feet or 4000 feet minimum ranges. Items should be sited so that lugs and/or strongbacks and nose and/or tail plate sections are oriented away from personnel locations*."

The distance in feet corresponding to 328W$^{1/3}$ (W in pounds) is based on overpressure, defining a location with a pressure level of 0.0655 psi (0.45 kPa or 147.1 dB peak flat sound pressure level). The requirement of a 2500 feet/4000 feet distance is a fragmentation requirement.

ACCIDENTAL DETONATIONS.

Again, until recently, Reference 1 gave the following guidance for fragmentation distances from accidental detonations: *"For all types of Hazard Division 1.1 in quantities of 101 to 450 lbs NEW (46 to 204 Kg NEQ), the minimum distance shall be given by the relationship: Minimum Distance = -1133.9 + 389 x ln(NEW) [NEW in pounds and Minimum Distance in feet, ln is* *natural logarithm], with a minimum distance of 670 feet. For NEWs in the range 450 to 30,000 lbs (204 to 13,600 Kg NEQ), the minimum distance shall be 1250 feet*."

The minimum distance corresponds to the range at which the density of hazardous fragments reaches a value of 1 fragment per 600 ft^2 (1 fragment per 55.7 m^2), where a hazardous fragment is defined as having an impact energy of 58 ft-lbs (79 Joules).

PROBLEMS WITH PREVIOUS REQUIREMENTS

Over the past few years, several problems had been identified with the requirements described above. In the area of intentional detonations, the 2500/4000 foot step function is not rational. Intuitively, smaller items should have shorter ranges. Research has shown that this requirement was based on expert judgement with no hard data as back up. For many items it was too conservative, i.e., it required greater ranges than necessary. For a few items, the specified range was too short.

The U.S. DoD requirements for accidental detonations of HD 1.2 materials also have recently been updated. Among other things, the 670-foot minimum structural debris distance for explosive weights less than 100 pounds has been eliminated. Instead, the minimum is now set at 200 feet with an equation and table providing the distances for other explosive weights. The consensus was that a similar approach should be applied to HD 1.1 items.

APPROACH

The approach that has been taken to address these issues is to use information that previously had been generated by the U.S. Army Engineering and Support Center, Huntsville (USAESCH) on the primary fragmentation characteristics of selected, naturally-fragmenting munition items—namely, the maximum fragment range and the hazardous fragment distance, i.e., the range at which the hazardous fragment density reaches a value of 1 per 600 ft^2. Currently, such calculations are being performed as part of Huntsville's support for unexploded ordnance (UXO) response operations.

PRIMARY FRAGMENT PREDICTION METHODOLOGY.

In order to calculate the fragmentation characteristics of a cased munition, USAESCH has developed techniques to model the item as a series of cylinders in contact with an explosive charge. Once such a model has been developed, a series of equations can be used to determine the fragmentation characteristics of each region of the model. The techniques used to calculate the fragmentation characteristics are described in TM 5-1300[2], "Structures to Resist the Effects of Accidental Explosions" and the modeling techniques are detailed in HNC-ED-CS-S-98-1[3], "Methods for Predicting Primary Fragmentation Characteristics of Cased Explosives". HNC documents are available from the USAESCH web site:

http://www.hnd.usace.army.mil/oew/tech/AnalyticalTools/analindx.htm

"The fragmentation pattern and the weight of the largest fragment resulting from the high-order detonation of an evenly-distributed explosive in a cylindrical metal case of uniform thickness have been calculated according to relationships developed on the basis of theoretical considerations confirmed with a large number of tests"[2].

Once calculated, the fragmentation characteristics may be used to determine fragment throw ranges, hazardous debris density or fragment penetration. Fragment throw range is determined using the initial fragment velocity and the appropriate fragment weight in a trajectory analysis such as the computer software TRAJ[4]. To determine the maximum fragment range, the range of the maximum weight fragment for each region of the model should be calculated and the largest of these ranges defined as the maximum fragment range of the munition.

Expanding upon these calculations, algorithms have been developed to calculate the range at which the primary fragment density from a cased, cylindrical munition equals one hazardous fragment per 600 ft^2. This method is detailed in HNC-ED-CS-S-98-2[5]. The method is based upon the primary fragmentation distribution model provided in NATO AASTP-1[6].

RESULTS

INTENTIONAL DETONATIONS.

Table 1 presents a summary of the maximum fragment ranges for many of the items that have been examined. Figure 1 is a plot of the ranges given in Table 1, as a function of the diameter of the item. Two additional curves are shown in this figure:

- The previous 2500/4000-foot values described at the beginning of this paper.
- An upper bound curve for the information presented.

TABLE 1. MAXIMUM CASE FRAGMENT RANGE FOR SELECTED, SINGLE WEAPON DETONATIONS

ITEM	MAXIMUM FRAGMENT RANGE* (feet)	ITEM	MAXIMUM FRAGMENT RANGE* (feet)
20-mm projectile	320	3-in Stokes mortar	1345
25-mm projectile	760	4-in Stokes mortar	1610
37-mm projectile	1180	M83, 4-lb fragmentation bomb	1365
40-mm projectile	1100	M41, 20-lb fragmentation bomb	2105
40-mm grenade	345	M3A1, 4.2-in mortar	1620
57-mm projectile	1030	Mark 1, 4.7-in	2540
M48, 75-mm projectile	1700	2.36-in rocket (case only)	810
M71, 90-mm	1955	M28A2, 3.5-in rocket (case only)	1420
M371, 90-mm HEAT	1545	M229, 2.75-in rocket	1375
M1, 105-mm projectile	1940	M8, 4.5-in rocket	1885
M356, 120-mm	2130	M49A3, 60-mm mortar	1080
British Naval Round, 4.5-in	2045	M56, 81-mm mortar	1215
MK 35, 5"/38 projectile	2205	M374, 81-mm mortar	1235
MK 64, 5"/54 projectile	1800	6-in trench mortar	2630
M107, 155-mm projectile	2580	M64A1, 500-lb bomb	2500
M122, 155-mm (chemical)	2165	MK 81, 250-lb bomb	2855
M795, 155-mm	2700	MK 82, 500-lb bomb	3180
M123, 165-mm	1925	MK 83, 1000-lb bomb	3290
M437, 175-mm projectile	2705	MK 84, 2000-lb bomb	3880
M106, 8-in projectile	3290	BLU-109 bomb	4890
MK 13 & MK 14, 16"/50 projectile	5640		

*Note: Range does not include shaped charge jet, base plates, nose plugs, or lugs

The curve fits associated with the upper bound curve of Figure 1 are presented in Table 2. These curve fits serve as the basis for Table 3 (new DoD 6055.9-STD Table C5.T1), which presents maximum fragment range as a function of item diameter for generic weapons. Munition specific calculations with appropriate safety factors using a DDESB-approved method may be used in lieu of Tables 1 and 2 to determine maximum fragment ranges.

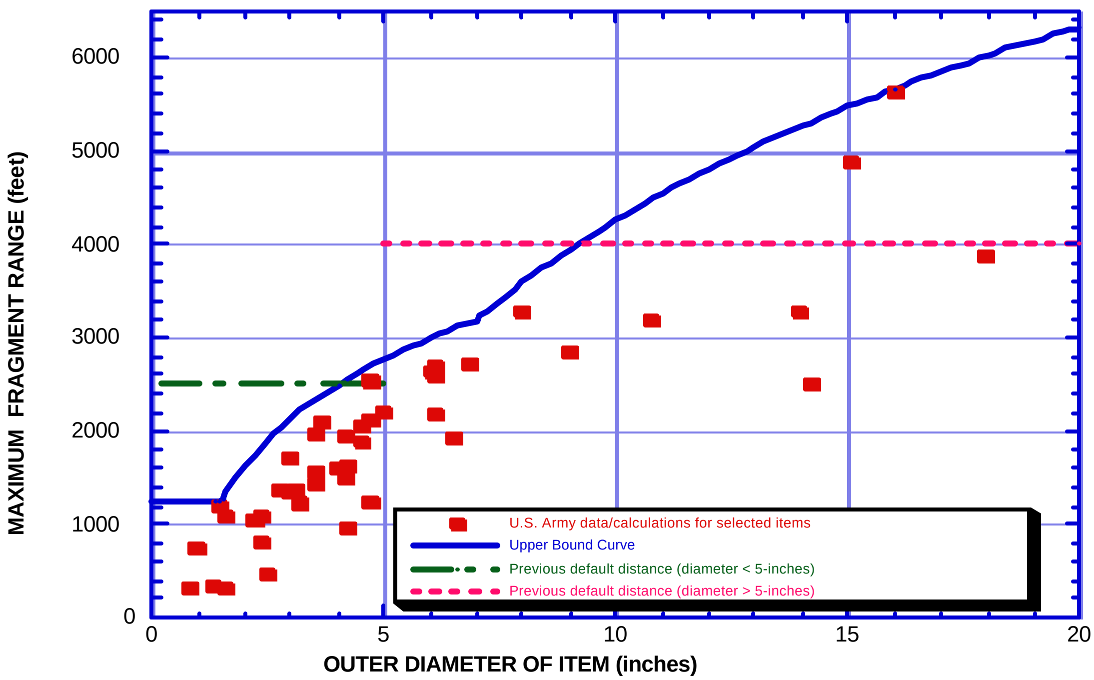


FIGURE 1. MAXIMUM FRAGMENT RANGES FOR INTENTIONAL DETONATIONS

TABLE 2. UPPER BOUND CURVE FITS—INTENTIONAL DETONATIONS

EQUATION	RANGE OF VALIDITY
Maximum Fragment Range = 759 + 1251*[ln(Diameter)] with a 1250-foot minimum distance	Diameter ≤ 7 inches
Maximum Fragment Range = -2641 + 2998*[ln(Diameter)]	Diameter > 7 inches
Diameter = exp[(Maximum Fragment Range/1251) – 0.61]	Range ≤ 3193 feet
Diameter = exp[(Maximum Fragment Range/2998) + 0.88]	Range > 3193 feet

(Note: in these equations, range is in feet, diameter in inches; exp (x) represents e^x and ln is the natural logarithm)

It should be emphasized that both Tables 1 and Table 3 apply to individual item detonations and do not apply to detonations involving stacks of items. The tables also do not address "rogue" fragments produced by sections of nose plugs, base plates and/or lugs. Those non-case fragments can travel to significantly greater distances than those shown in these tables (distances greater than 10,000 feet).

When performing intentional detonations, care must be taken to properly orient the item or take other measures to minimize or eliminate this effect. Note: Items shall always be sited so that lugs and/or strongbacks and nose and/or tail plate sections are oriented away from personnel locations. When detonations involve multiple rounds, the preferred approach is as follows:

(1) Munitions shall be placed in a single layer with their sides touching such that their axis is horizontal;

(2) The munitions shall be placed so that the nose of each item is pointing in the same direction;

(3) Munitions shall be oriented so that lugs and/or strongbacks and nose and/or tail plate sections (rogue fragments) are facing away from areas to be protected;

(4) The consolidated shot shall be initiated in such a manner that detonation of all items is simultaneous.

TABLE 3. MAXIMUM FRAGMENT RANGES FOR INTENTIONAL DETONATIONS OF GENERIC ITEMS

DIAMETER (in)	MAXIMUM FRAGMENT RANGE (feet)	DIAMETER (in)	MAXIMUM FRAGMENT RANGE (feet)
		10.5	4408
<1.5	1250	11.0	4548
1.5	1266	11.5	4681
2.0	1626	12.0	4809

2.5	1905	12.5	4931
3.0	2133	13.0	5049
3.5	2326	13.5	5162
4.0	2493	14.0	5271
4.5	2641	14.5	5376
5.0	2772	15.0	5478
5.5	2892	15.5	5576
6.0	3000	16.0	5671
6.5	3101	16.5	5763
7.0	3193	17.0	5853
7.5	3400	17.5	5940
8.0	3593	18.0	6024
8.5	3775	18.5	6106
9.0	3946	19.0	6186
9.5	4108	19.5	6264
10.0	4262	20.0	6340

When these procedures are not followed but the orientation of the rogue fragments can be controlled, then the ranges given in Tables 1 and 3 must be increased by 20% to account for interaction effects resulting from the detonation of multiple rounds. The 20% increase in range is based on the results of a series of trajectory calculations using the computer code TRAJ[4]. When multiple rounds are arranged in stacks in which the orientation of individual items cannot be controlled, fragment ranges must be evaluated on a case-by-case basis. When detonations involve stacks of mixed munition types, evaluate the ranges for each type separately using the procedures just presented and use the larger of the ranges that are obtained.

ACCIDENTAL DETONATIONS.

The fragmentation range that has been defined for accidental detonations is the range at which the density of hazardous fragments reaches a value of 1 per 600 ft^2, hereafter referred to as the hazardous fragment distance. Table 4 presents a summary of some of the hazardous fragment distances for munitions that have been examined thus far.

Figure 2 is a plot of the ranges given in Table 4 as a function of the Net Explosive Weight (NEW) of the item. Three additional curves are shown in this figure:

- The current curve from DoD 6055.9-STD for NEW > 100 pounds
- The previous requirement from DoD 6055.9-STD for NEW $\leq$ 100 pounds
- An Upper Bound curve for the data presented

TABLE 4. HAZARDOUS FRAGMENT DISTANCES FOR SELECTED SINGLE-ITEM DETONATIONS

ITEM	HAZARDOUS FRAGMENT DISTANCE[1,2] (feet)	ITEM	HAZARDOUS FRAGMENT DISTANCE[1,2] (feet)
20-mm projectile	200	3-in Stokes mortar	220
25-mm projectile	200	4-in Stokes mortar	315

37-mm projectile	200	M83, 4-lb fragmentation bomb	210
40-mm projectile	200	M41, 20-lb fragmentation bomb	275
40-mm grenade	200	M3A1, 4.2-in mortar	310
57-mm projectile	200	Mark 1, 4.7-in	320
M48, 75-mm projectile	235	2.36-in rocket (case only)	200
M71, 90-mm	250	M28A2, 3.5-in rocket (case only)	235
M371, 90-mm HEAT	210	M229, 2.75-in rocket	300
M1, 105-mm projectile	340	M8, 4.5-in rocket	360
M356, 120-mm	385	M49A3, 60-mm mortar	200
British Naval Round, 4.5-in	355	M56, 81-mm mortar	220
MK 35, 5"/38 projectile	300	M374, 81-mm mortar	235
MK 64, 5"/54 projectile	325	6-in trench mortar	365
M107, 155-mm projectile	445	M64A1, 500-lb bomb	680
M122, 155-mm (chemical)	365	MK 81, 250-lb bomb	585
M795, 155-mm	435	MK 82, 500-lb bomb	690
M123, 165-mm	340	MK 83, 1000-lb bomb	815
M437, 175-mm projectile	525	MK 84, 2000-lb bomb	925
M106, 8-in projectile	530	BLU-109 bomb	880
MK 13 & MK 14, 16"/50 projectile	550		

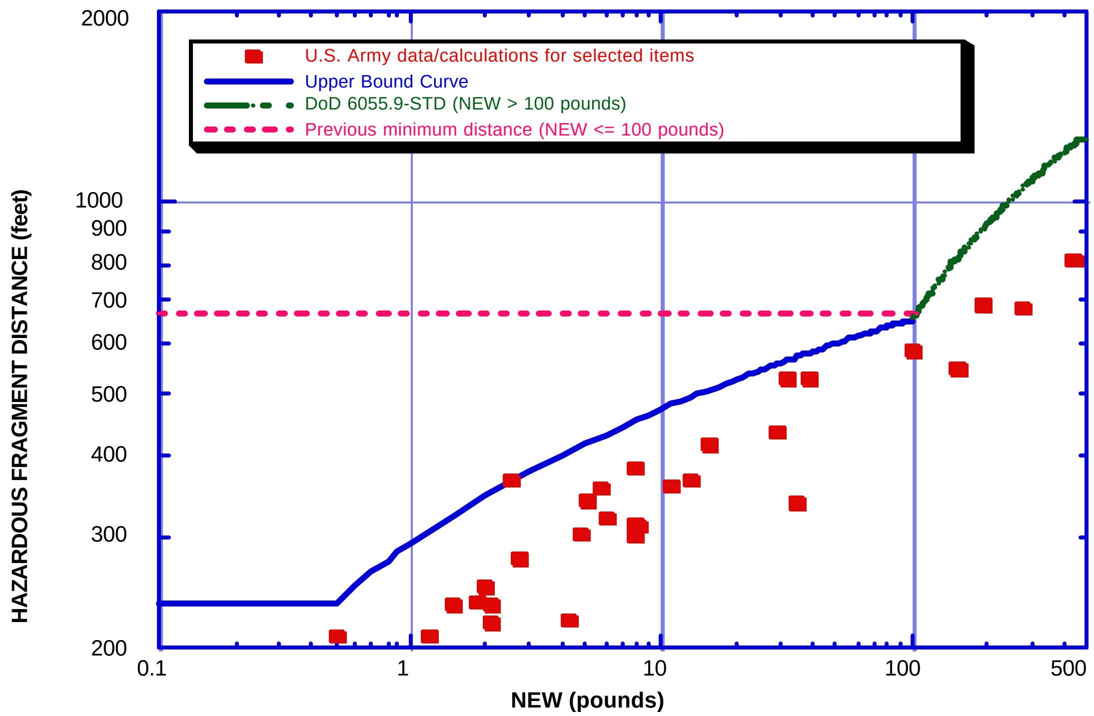
(1) Distance does not include shaped charge jet, base plates, nose plugs, or lugs
(2) 200-feet represents a minimum distance that is assigned by the methodology

The curve fits associated with the upper bound curve of Figure 2 are presented in Table 5 (Note: In the above equations, Distance is in feet and NEW is in pounds, ln is natural logarithm and exp is e^{x}). These curve fits serve as the basis for Table 6 (new DoD 6055.9-STD Table C2.T1), which presents hazardous fragment distance as a function of item NEW for generic weapons. Munition specific calculations with appropriate safety factors using a DDESB-approved method may be used in lieu of Tables 5 and 6 to determine hazardous fragment distances.

TABLE 5. UPPER BOUND CURVE FITS—ACCIDENTAL DETONATIONS

EQUATION	RANGE OF VALIDITY
Hazardous Fragment Distance = 291.3 + 79.2*[ln(NEW)] with a 236-foot minimum distance	NEW < 100 pounds
Hazardous Fragment Distance = -1133.9 + 389*[ln(NEW)]	100 pounds < NEW < 450
NEW = exp[(Hazardous Fragment Distance/79.2) – 3.678]	Hazardous Fragment Distance < 658 feet
NEW = exp[(Hazardous Fragment Distance/389) + 2.914]	658 < Hazardous Fragment Distance < 1250 feet

As was emphasized in the "Intentional Detonation" section, both Tables 4 and Table 6 apply to individual item detonations and do not apply to detonations involving stacks of items. These tables also do not address "rogue" fragments produced by sections of nose plugs, base plates and/or lugs.



U.S. Army data/calculations for selected items
Upper Bound Curve
DoD 6055.9-STD (NEW > 100 pounds)
Previous minimum distance (NEW <= 100 pounds)
HAZARDOUS FRAGMENT DISTANCE (feet)
2000
1000
900
800
700
600
500
400
300
200
0.1
1
10
100
500
NEW (pounds)

FIGURE 2. HAZARDOUS FRAGMENT DISTANCES FOR ACCIDENTAL DETONATIONS

TABLE 6. HAZARDOUS FRAGMENT DISTANCES ASSOCIATED WITH SINGLE-ITEM DETONATIONS OF GENERIC ITEMS

NEW (pounds)	HAZARDOUS FRAGMENT DISTANCE (feet)	NEW (pounds)	HAZARDOUS FRAGMENT DISTANCE (feet)
≤ 0.5	236	80	638
1	291	85	643
2	346	90	648
4	401	95	652
6	433	100	658
8	456	125	744
10	474	150	815
15	506	175	875
20	529	200	927
25	546	225	973
30	561	250	1014
35	573	275	1051
40	583	300	1085
45	593	325	1116
50	601	350	1145
55	609	375	1172
60	616	400	1197
65	622	425	1220
70	628	450	1243
75	633	> 450	1250

RECENTLY APPROVED CHANGES TO DOD 6055.9-STD

The information that has been presented in this paper forms the basis and justification for recent changes to DoD 6055.9-STD. These changes were approved in June 2000 and are available from the DDESB homepage:

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REFERENCES

1. DoD 6055.9-STD, "DoD Ammunition and Explosives Safety Standards," Department of Defense, July 1999.

2. TM 5-1300, "Structures to Resist the Effects of Accidental Explosions," Department of the Army, November 1990.

3. HNC-ED-CS-S-98-1, "Methods for Predicting Primary Fragmentation Characteristics of Cased Explosives," U. S. Army Corps of Engineers Engineering and Support Center, Huntsville, AL, January 1998.

4. Montanaro, P.E., "TRAJ – A Two Dimensional Trajectory Program for Personal Computers," Minutes of the 24th Explosives Safety Seminar, August 1990, pp. 1853-1879.

5. HNC-ED-CS-S-98-2, "Method for Calculating Range to No More Than One Hazardous Fragment per 600 Square Feet," U.S. Army Corps of Engineers Engineering and Support Center, Huntsville, AL, January 1998.

6. NATO AASTP-1, Edition 1, "Manual Of NATO Safety Principles for the Storage of Military Ammunition and Explosives," North Atlantic Treaty Organization, August 1997.